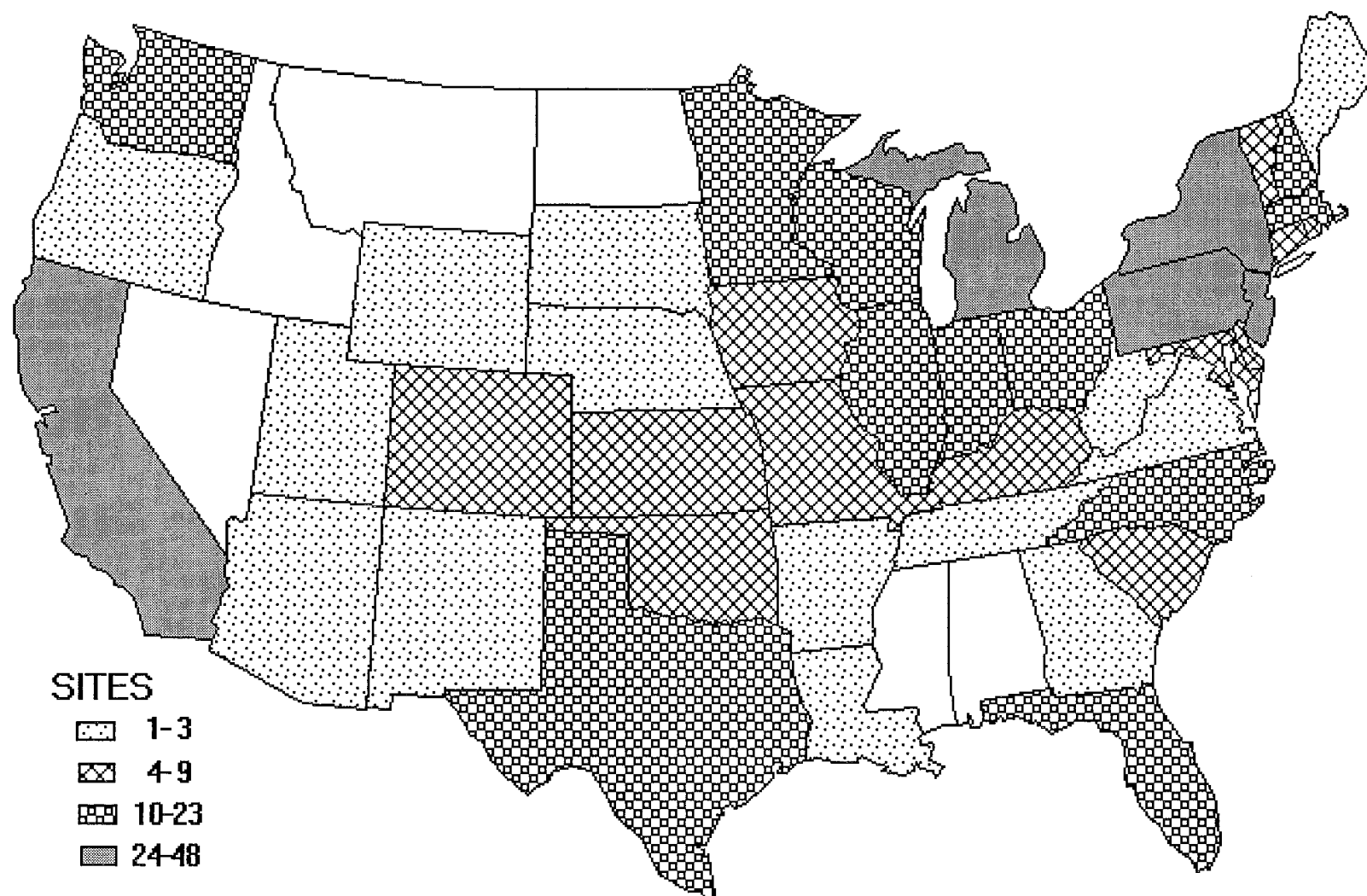# 5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

Vinyl chloride has been found in at least 496 of the 1,430 current or former EPA National Priorities List (NPL) (HAZDAT 1996). However, the number of sites evaluated for vinyl chloride is not known.

The frequency of these sites within the United States can be seen in Figure 5-1. Of these sites, 495 are located in the United States and 1 is located in the Commonwealth of Puerto Rico (not shown). Of the environmental media tested at NPL sites, groundwater was most frequently found to be contaminated with vinyl chloride (HAZDAT 1996).

Vinyl chloride is used almost exclusively in the United States by the plastics industry for the production of PVC and several copolymers. Anthropogenic sources are responsible for all of the vinyl chloride found in the environment. Most of the vinyl chloride released to the environment is eventually transported to the atmosphere. Lesser amounts are transported to groundwater. Vinyl chloride has been detected in the ambient air in the vicinity of vinyl chloride and PVC manufacturing plants and hazardous waste sites. The compound has also leached into groundwater from spills, landfills, and industrial sources; it can also enter groundwater after being produced by the bacterial degradation of trichloroethylene, tetrachloroethylene, and 1,l ,I-trichloroethane (Smith and Dragun 1984).

Effluents and emissions from vinyl chloride and PVC manufacturers are responsible for most of the vinyl chloride released to the environment. When released to the atmosphere, vinyl chloride is expected to be removed by reaction with photochemically generated hydroxyl radicals (half-life = l-2 days). Reaction products include hydrochloric acid, formaldehyde, formyl chloride, acetylene, chloroacetaldehyde, chloroacetylchloranil, and chloroethylene epoxide. In photochemical smog, the half-life of vinyl chloride is reduced to a few hours. When released to water, volatilization is expected to be the primary fate process. In waters containing photosensitizers, such as humic materials, sensitized photodegradation may also be important. When released to soil, vinyl chloride either volatilizes rapidly from soil surfaces or leaches readily through soil, ultimately entering groundwater.

FIGURE 5-1 FREQUENCY OF NPL SITES WITH VINYL CHLORIDE CONTAMINATIONS*

SITES

- ☐ 1-3
- ☒ 4-9
- ▦ 10-23
- ▨ 24-48

*Derived from HAZDAT 1996

Segments of the general population living in the vicinity of emission sources are exposed to vinyl chloride by inhalation of contaminated air. Average daily intake of vinyl chloride by inhalation for these people ranges from trace amounts to 2,100 pg/day. The average daily intake of vinyl chloride by inhalation is expected to be essentially zero for the remainder of the population. The majority of the general population is not expected to be exposed to vinyl chloride through ingestion of drinking water. The average daily intake of vinyl chloride through the diet is predicted to be essentially zero. Workers, particularly in plastic industries, are exposed to vinyl chloride mainly by inhalation, with some absorption through the skin possible. The National Occupational Exposure Survey (NOES), conducted by NIOSH from 1981 to 1983, estimated that 81,314 workers employed at 3,711 plant sites were potentially exposed to vinyl chloride (NOES 1990).

5.2 RELEASES TO THE ENVIRONMENT

5.2.1 Air

The major source of vinyl chloride releases to the environment is believed to be emissions and effluents from plastic industries, primarily vinyl chloride and PVC manufacturers. Worldwide emissions of vinyl chloride into the atmosphere during 1982 totalled approximately 400 million pounds (Hartmans et al. 1985). Another emission source is tobacco smoke which has been found to contain 5.6-28 ng vinyl chloride per cigarette (Hoffman et al. 1976). According to TRI data for 1993 (TRI93 1995), an estimated total of 1.01 million pounds of vinyl chloride, amounting to 99.9% of the total environmental releases, was discharged to the air from the manufacturing and processing facilities in the United States in 1993 (Table 5-l). The data listed in the TRI should be used with caution because only certain types of facilities are required to report. This is not an exhaustive list.

5.2.2 Water

Vinyl chloride released in waste water from the plastics industries is expected to volatilize fairly rapidly (on the order of hours to days) into the atmosphere. Anaerobic reductive dehalogenation of trichloroethylene, tetrachloroethylene, and l,l, 1-trichloroethane also releases vinyl chloride into groundwater at hazardous waste sites (Smith and Dragun 1984) or other locations where the proper conditions are found in the subterranean strata. Vinyl chloride leaches into groundwater from spills,

Table 5-1. Releases to the Environment from Facilities That Manufacture or Process Vinyl Chloride

			Reported amounts released in pounds per year						
State[a]	City	Facility	Air	Water	Land	Underground injection	Total environment[b]	POTW transfer	Off-site waste transfer
CA	SAUGUS	NA	849				849	21	
CA	TORRANCE	UNION CARBIDE CORP.	17				17		
DE	DELAWARE CITY	GEORGIA GULF CORP.	27,600	1			27,601		5
DE	DELAWARE CITY	FORMOSA PLASTICS CORP. USA	111,227				111,227		
FL	PACE	WESTLAKE VINYLS CORP.	9,994				9,994		44
IL	HENRY	GEON CO.	40,700				40,700		790
IL	ILLIOPOLIS	BORDEN INC.	88,667	30			88,697		946
KY	CALVERT CITY	NA	143				143		
KY	ITY	WESTLAKE GROUP	12,699				12,699		402
KY	CALVERT CITY	WESTLAKE CHEMICAL CORP.	18,140				18,140		54,229
KY	LOUISVILLE	BF GOODRICH CO.	2,320				2,320		15
KY	LOUISVILLE	GEON CO.	2,362				2,362	251	
LA	ADDIS	OCCIDENTAL PETROLEUM CORP.	17,600	8			17,608		1
LA	BATON ROUGE	FORMOSA PLASTICS CORP. USA	12,763	50			12,813		1
LA	BATON ROUGE	RHONE-POULENC INC.	269				269		17
LA	GEISMAR	NA	650				650		
LA	GEISMAR	NA	33,859	12			33,871		35
LA	LAKE CHARLES	PPG IND. INC.	21,000				21,000		
LA	PLAQUEMINE	NA	15,900				15,900		
LA	PLAQUEMINE	DOW CHEMICAL CO.	4,960	2			4,962		

Table 5-1. Releases to the Environment from Facilities That Manufacture or Process Vinyl Chloride (continued)

			Reported amounts released in pounds per year						
State[a]	City	Facility	Air	Water	Land	Underground injection	Total environment[b]	POTW transfer	Off-site waste transfer
LA	SULPHUR	NA	15,000				15,000		5
LA	WESTLAKE	NA	4,884	3			4,887		1,137
MI	MIDLAND	DOW CHEMICAL CO.	854				854		
MO	KANSAS CITY	MILES INC.	1,460				1,460		
MS	ABERDEEN	NA	42,644	31			42,675		
NJ	BURLINGTON	OCCIDENTAL PETROLEUM CORP.	15,700	66			15,766	,	5
NJ	PEDRICKTOWN	GEON CO.	33,000	12			33,012		124
NY	NIAGARA FALLS	GOODYEAR TIRE & RUBBER CO.	70,423				70,423	29	5
OH	AVON LAKE	GEON	4,800				4,800	29	210
OK	OKLAHOMA CITY	NA	21,500				21,500		4
PA	POTTSTOWN	OCCIDENTAL PETROLEUM CORP.	118,400			6	118,406	10	9,750
TX	DEER PARK	OCCIDENTAL PETROLEUM CORP.	9,700				9,700		101
TX	DEER PARK	GEON CO.	1,444				1,444		21,335
TX	FREEPORT	SHIN ETSU	94,374	30			94,404		
TX	FREEPORT	DOW CHEMICAL USA	17,050	11			17,061		
TX	GARLAND	UNION CARBIDE	8				8		
TX	GREGORY	OCCIDENTAL PETROLEUM CORP.	148				148		
TX	LA PORTE	OCCIDENTAL PETROLEUM CORP.							
TX	LA PORTE	GEON CO.	6,584				6,584		

Table 5-1. Releases to the Environment from Facilities That Manufacture or Process Vinyl Chloride (continued)

State[a]	City	Facility	Reported amounts released in pounds per year						
			Air	Water	Land	Underground injection	Total environment[b]	POTW transfer	Off-site waste transfer
TX	PASADENA	OCCIDENTAL PETROLEUM CORP.	84,400	4			84,404		
TX	POINT COMFORT	FORMOSA PLASTICS CORP. USA	36,246	17			36,263		98,324
TX	TEXAS CITY	UNION CARBIDE CORP.	13,589				13,589	3	1
VA	PULASKI	NA	10				10		18,902
		Totals	1,013,937	277	6		1,014,220	343	206,388

Source: TRI93 1995

[a] Post office state abbreviations used
[b] The sum of all releases of the chemical to air, land, water, and underground injection wells by a given facility

NA = not available; POTW = publicly owned treatment works

landfills, and industrial sources (e.g., the plastics industry). According to data collected from the analysis of leachates and monitoring wells at sites where groundwater was contaminated by municipal solid waste landfill leachate, vinyl chloride was present in both the leachates and the groundwater samples (Sabel and Clark 1984). Vinyl chloride has been found in groundwater at other landfills also (ATSDR 1995a, 1995b).

According to TRI data for 1993 (TR193 1995), an estimated total of 277 pounds of vinyl chloride, constituting less than 0.03% of the total environmental releases, was discharged to the water from the manufacturing and processing facilities in the United States in 1993 (Table 5-1). The data listed in the TRI should be used with caution because only certain types of facilities are required to report. This is not an exhaustive list.

5.2.3 Soil

Vinyl chloride can either enter the soil from leachates at hazardous waste sites or enter the ground via underground injection. Release through either of these mechanisms is, however, only a small fraction of the total environmental discharge. According to TRI data for 1993 (TR193 1995), an estimated total of 6 pounds of vinyl chloride, amounting to less than 0.0006% of the total environmental releases, was discharged to the soil from manufacturing and processing facilities in the United States in 1993 (Table 5-l). Among the total 1.01 million pounds of vinyl chloride discharged to the environment, none was reported to have been injected to the underground. The data listed in the TRI should be used with caution because only certain types of facilities are required to report. This is not an exhaustive list.

5.3 ENVIRONMENTAL FATE

5.3.1 Transport and Partitioning

Based on a vapor pressure of 2,660 mmHg at 25°C essentially all vinyl chloride in the atmosphere is expected to exist in vapor form (Eisenreich et al. 1981; Verschueren 1983). Consequently, removal from the atmosphere by dry deposition is not expected to be an important fate process.

5. POTENTIAL FOR HUMAN EXPOSURE

The primary removal process for vinyl chloride from natural water systems is volatilization into the atmosphere. Henry's law constant value of 1.2 atm-m^3/mol at 10°C indicates that vinyl chloride should partition rapidly to the atmosphere. The half-life for vinyl chloride volatilization from a typical pond, river, and lake has been estimated to be 43.3, 8.7, and 34.7 hours, respectively. These values are based on an experimentally determined reaeration rate ratio of approximately 2 and assumed oxygen reaeration rates of 0.008, 0.04, and 0.01 per hour for a typical pond, river, and lake, respectively (EPA 1982a). Predicted half-lives should be considered rough estimates since the presence of various salts in natural water systems may affect the volatility of vinyl chloride significantly (EPA 1979d). Many salts have the ability to form complexes with vinyl chloride and can increase its water solubility; therefore, the presence of salts in natural waters may significantly influence the amount of vinyl chloride remaining in the water (EPA 1979d). The half-life of vinyl chloride in bodies of water is also affected by depth and turbidity.

The relatively high vapor pressure of vinyl chloride indicates that the compound volatilizes quite rapidly from dry soil surfaces (Verschueren 1983). The effective half-life (due to volatilization and degradation) of vinyl chloride placed 10 cm deep in dry soil is predicted to be 12 hours (Jury et al. 1984). Vinyl chloride is soluble in water and thus can leach through the soil and travel to groundwater before evaporation can occur (Cowfer and Magi&o 1983).

Experimental data regarding adsorption of vinyl chloride to soil were not located. Based on the regression equations given by Lyman et al. (1982), Sabljic (1984), and Kenaga and Goring (1980), the soil organic carbon adsorption coefficient (K_{oc}) for vinyl chloride was estimated to range from 14 to 13 1. These K_{oc} values suggest a very low sorption tendency, meaning that this compound would be highly mobile in soil. Thus, vinyl chloride has the potential to leach into groundwater.

Vinyl chloride is soluble in most common organic solvents (Cowfer and Magistro 1983). In situations where organic solvents exist in relatively high concentrations (e.g., landfills, hazardous waste sites), cosolvation of vinyl chloride could have the effect of reducing its volatility, thus causing it to have even greater mobility than indicated by estimated K_{oc} values.

Vinyl chloride's high vapor pressure and low octanol/water partition coefficient (log K_{ow} = 1.23) indicates that it bioaccumulates to a very limited extent (EPA 1982a). The bioconcentration factor (BCF) of an organic chemical can be estimated from the K_{ow} or water solubility. Based on the

regression equation given by Veith et al. (1980), the estimated BCF of 5.1 indicates limited bioconcentration in aquatic organisms. Freitag et al. (1985) measured BCFs in algae, fish, and activated sludge. The BCFs for algae, fish, and activated sludge were 40, less than 10, and 1,100, respectively. The very low value for fish, in comparison to the algae and activated sludge, may suggest a detoxification process in more highly developed organisms such as fish. Lu et al. (1977) examined the bioaccumulation of ^{14}C -vinyl chloride in a closed model aquatic ecosystem over a 3-day period. The high volatility of vinyl chloride minimized any potential bioaccumulation. Relatively low tissue concentrations found in fish suggested that vinyl chloride is not biomagnified in aquatic food chains to any substantial degree.

5.3.2 Transformation and Degradation

5.3.2.1 Air

Reaction of vinyl chloride vapor with photochemically generated hydroxyl radicals is predicted to be the primary degradation mechanism for this compound in the atmosphere (Cox et al. 1974; Howard 1976; Perry et al. 1977). Products of this reaction are hydrochloric acid, formaldehyde, for-my chloride, carbon monoxide, carbon dioxide, chloroacetaldehyde, acetylene, chloroethylene epoxide, chloroacetylchloranil, and water (Muller and Korte 1977; Woldbaek and Klaboe 1978). Under conditions of photochemical smog, the half-life of vinyl chloride would be reduced to a few hours (Carassiti et al. 1978). Reaction with ozone and direct photolysis are less important degradation mechanisms of vinyl chloride in the atmosphere (EPA 1976a, 1985c; Zhang et al. 1983). Vinyl chloride in the vapor phase does not absorb light of wavelengths above 220 nm (EPA 1976a). Since atmospheric ozone blocks almost all sunlight with wavelengths less than 295 nm, direct photolysis is likely to occur very slowly, if at all, in the atmosphere (EPA 1976a).

5.3.2.2 Water

The primary removal process for vinyl chloride from surface waters is volatilization into the atmosphere. Vinyl chloride in water does not absorb ultraviolet radiation above 218 nm; therefore, direct photolysis in the aquatic environment is also expected to occur very slowly, if at all (EPA 1976a). No photolysis occurred over a go-hour period. In waters containing photosensitizers, such as

humic materials, photodegradation may be fairly rapid. If so, in some waters, sensitized photodegradation may also be an important removal mechanism (EPA 1976a).

The hydrolytic half-life of vinyl chloride has been estimated to be less than 10 years at 25°C (EPA 1976a). Since the volatilization rate of vinyl chloride is much more rapid than the predicted rate of hydrolysis, hydrolysis is not a significant aquatic fate (EPA 1976a, 1979d). Vinyl chloride is not oxidized chemically by reaction with photochemically generated molecular oxygen in natural water systems (EPA 1976a). Experiments carried out at 20 mg/L vinyl chloride in water saturated with molecular oxygen at elevated temperatures showed that, after 12 hours at 85°C no degradation of vinyl chloride could be detected. At temperatures and oxygen concentrations in natural waters, therefore, vinyl chloride will not be degraded by molecular oxygen at a significant rate (EPA 1976a).

EPA (1977) observed no change in the biochemical oxygen demand in raw sewage seed (used as a microbial inoculum) and raw sewage seed plus vinyl chloride at 20°C over a 25-day period. The study authors interpreted this to mean that no biodegradation of vinyl chloride occurred. However, more recent data has shown that vinyl chloride can undergo microbial degradation. *Rhodococcus* sp. strains SM-1 and Wrink, which were isolated from a trichloroethylene-degrading bacterial mixture, and *Rhodococcus* rhodochrous ATCC 21197 were shown to degrade >99.9% of vinyl chloride within 7 days (Malachowsky et al. 1994). No significant differences in the amount of vinyl chloride degraded were found among the three organisms. The majority (66-83%) of the labelled carbon was converted to carbon dioxide (CO_2).

Vinyl chloride (1 ppm) was rapidly degraded under aerobic conditions in a laboratory study that used soil-water microcosms from aquifer material without the addition of other nutrients, such as nitrogen and phosphorus (Davis and Carpenter 1990). About 25% of the vinyl chloride was degraded after 1 week and more than 99% was degraded after 108 days. Sixty-five percent of labeled vinyl chloride was recovered as $^{14}C O_2$, after 108 days, demonstrating the extent of the mineralization.

Strain SM-1, a member of the order *Actinomycetules,* obtained from a trichloroethylene-degrading consortium was found to mineralize vinyl chloride to CO_2 by using propane as an energy source during growth experiments or cell suspension experiments (Phelps et al. 1991). Vinyl chloride concentrations decreased by more than 90%; growth cultures and cell suspensions incorporated about

10% of the transformed vinyl chloride into biomass (Phelps et al. 1991). Mycobacterium vaccae JOB5 degraded 100% of vinyl chloride in a 2-hour incubation (Wackett et al. 1989).

5.3.2.3 Sediment and Soil

Most vinyl chloride present on soil surfaces will volatilize to the atmosphere. Vinyl chloride is also mobile in soil and susceptible to leaching (Lyman et al. 1982). The presence of other organic solvents, such as those found at hazardous waste sites, may affect the mobility of the substance in the soil (Cowfer and Magistro 1983). Photodegradation on the surface of soils is expected since sensitized photodegradation in water occurs.

Several laboratory studies have indicated that both aerobic and anaerobic biodegradation of vinyl chloride can occur in soils and aquifer materials via a number of mechanisms (Barrio-Lage et al. 1990; Castro et al. 1992a, 1992b; Davis and Carpenter 1990), although these degradation processes were generally slow. More recently, Nelson et al. (1993) investigated methanotrophic degradation of vinyl chloride using a laboratory-scale, methanotrophic, attached-film, expanded-bed bioreactor. They found that this technique is an efficient way to degrade vinyl chloride, with the removal efficiency greater than 90%.

5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

5.4.1 Air

Air in rural/remote and urban/suburban areas of the United States typically contains no detectable amount of vinyl chloride (EPA 1982f; Grimsrud and Rasmussen 1975a, 1975b; Harkov et al. 1984; Stephens et al. 1986; Wallace et al. 1984). Limited monitoring data indicate that in areas near vinyl chloride and PVC manufacturing facilities, the concentration of vinyl chloride in air typically ranges from trace levels to 105 μg/m^3 (0.041 ppm) (EPA 1979a, 1982f; Gordon and Meeks 1977) but may exceed 2,600 μg/m^3 (1 ppm) (Fishbein 1979). Elevated levels of vinyl chloride may also be found in the vicinity of hazardous waste sites and municipal landfills. Concentrations ranging from below detection limits to 5-8 μg/m^3 (0.002-0.003 ppm) have been measured in the air above some landfills (Baker and Mackay 1985; Stephens et al. 1986). Homes near one hazardous waste site in southern California were found to contain levels as high as 1,040 μg/m^3 (0.4 ppm) (Stephens et al. 1986) and

homes near another site between 1 and 9 ppb (Miller and Beizer 1985). Gaseous emissions from 20 Class II (nontoxic) landfills in southern California were analyzed for vinyl chloride (Wood and Porter 1987). Vinyl chloride was found in emissions from 85% of the landfills tested, and concentrations greater than 2,600 $\mu g/m^3$ (1 ppm) were detected in more than half of the landfill emissions. The concentrations of vinyl chloride measured in this study ranged from 0.624 to 114.4 mg/m^3 (0.24-44 ppm). Based on their observations, the study authors concluded that the presence of vinyl chloride at these landfills was due to either illegal disposal or in situ generation by the degradation of chlorinated solvents by bacteria and other microbes (Wood and Porter 1987).

5.4.2 Water

Vinyl chloride has been detected at varying concentrations in surface water, groundwater, and drinking water throughout the United States. Concentrations of vinyl chloride in drinking water wells and surface water in New York State were found to be 50 $\mu g/L$ (0.05 ppm) and 10 $\mu g/L$ (0.01 ppm), respectively (Burmaster 1982). Monitoring studies in nine states have identified concentrations as high as 380 $\mu g/L$ (0.38 ppm) in groundwater (Dyksen and IHess 1982).

The level of vinyl chloride in groundwater in the United States was determined during the 1982 EPA Groundwater Supply Survey (Westrick et al. 1984). Water supplies from 945 sites throughout the United States were studied. Vinyl chloride was positively identified in only 0.74% of the 945 groundwater supplies (detection limit 0.001 ppm). It was reported that 0.5% of 186 random sample sites and 3.8% of 158 nonrandom sample sites contained detectable levels of vinyl chloride. The maximum concentrations at the random and nonrandom sites were 1.1 $\mu g/L$ (0.0011 ppm) and 8.4 $\mu g/L$ (0.0084 ppm), respectively (Westrick et al. 1984). Approximately half of the samples were taken from a random list of water systems, which were subdivided into two sets of systems-those serving fewer than 10,000 people and those serving more than 10,000 people. The nonrandom samples were taken from systems selected by the states, using groundwater sources that were likely to show volatile organic compounds in drinking water (Westrick et al. 1984). Other studies have reported the occurrence of vinyl chloride in groundwater samples collected throughout the United States at levels at or below 380 $\mu g/L$ (0.38 ppm) (Cotruvo 1985; EPA 1982f; Goodenkauf and Atkinson 1986; Stuart 1983).

5.4.3 Sediment and Soil

Monitoring data for vinyl chloride in soil were not located in the available literature.

5.4.4 Other Environmental Media

In the past, vinyl chloride has been detected in various foods and bottled drinking water as a result of migration from PVC food wrappings and containers (Benfenati et al. 1991; Gilbert et al. 1980). Vinyl chloride has been found in vinegar at levels up to 98,000 μg/L (98 ppm), in edible oils at 300-1,800 μg/L (0.3-1.8 ppm), and in alcoholic beverages at 0.0-8,400 μg/L (0.0-8.4 ppm) when these foods were packaged and stored in PVC containers (Williams 1976; Williams and Miles 1975). Current data on levels of vinyl chloride in different foods were not located. At present, FDA regulates the use of PVC polymers in food packaging materials and the amount of residual monomer in polymers. In a modeling study using liquid chromatography to simulate migration conditions of vinyl chloride from PVC in actual food packaging and storage, it was shown that at the very low concentrations (less than 1 ppm) of residual vinyl chloride monomer in PVC packaging material, "essentially zero" migration of the vinyl chloride monomer into foods occurs (Kontominas et al. 1985). Vinyl chloride levels were determined in Italian drinking water bottled in PVC; levels ranged from 13 to 83 ppt (mean, 48 ppt) (Benfenati et al. 1991). It was also determined that there was a progressive migration of vinyl chloride from the bottle to the water, which occurred at a rate of 1 ng/L/day (Benfenati et al. 1991).

Vinyl chloride has been detected in drinking water. A study by EPA (1982f) estimated that 12 of 11,202 public water supplies that used surface water as their primary source had levels of vinyl chloride between 1.0 μg/L (0.001 ppm) and 5.0 μg/L (0.005 ppm); none had levels above 5 μg/L (0.005 ppm). Another study found that drinking water that ran through PVC pipes contained vinyl chloride at 1.4 μg/L (0.0014 ppm), whereas water that ran through a PVC system 9 years older contained 0.03-0.06 μg/L (0.03-0.06 ppb) (Dressman and McFarren 1978). The amount of vinyl chloride migrating from rigid PVC water pipes into drinking water was directly proportional to the residual level of vinyl chloride in the pipe itself. Current data on levels of vinyl chloride in drinking water and on the potential for leaching of vinyl chloride monomer from PVC pipes were not located. Under certain test conditions, vinyl chloride monomer in drinking water reacts with chlorine and is converted to chloroacetaldehyde and chloroacetic acid (Ando and Sayato 1984). Information

concerning the effect of this reaction on drinking water supplies that are treated with chlorine and the extent of this reaction was not stated.

During an EPA study, detectable levels of vinyl chloride monomer were found in indoor air samples taken from two of seven new 1975 model cars. Levels of vinyl chloride in indoor air in the two cars ranged from 400 to 1,200 μg/L (0.4-1.2 ppm). Ventilation of the car interiors led to the dissipation of vinyl chloride. The cars involved in the study had a high ratio of plastic to interior volume and were expected to provide worst-case concentrations for vinyl chloride in interior car air (EPA 1976b). Because of the limited nature of these data and the fact that this study is somewhat dated, no conclusions can be drawn regarding levels of vinyl chloride monomer in interior air of cars currently being produced.

Vinyl chloride has been detected in tobacco smoke. Cigarette smoke and smoke from small cigars has been found to contain 5.6-27 ng vinyl chloride per cigarette (Hoffman et al. 1976). The study authors suggested that the inorganic chloride concentrations in the tobacco determine the amount of vinyl chloride formed upon combustion of tobacco and released into the smoke (Hoffman et al. 1976).

5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

Inhalation is the most probable route of exposure for the general population. Typical values for the average daily intake of vinyl chloride by inhalation in urban/suburban and rural/remote areas not near emission sources have been estimated to be essentially zero. Assuming that the average adult intake of air is 20 m^3/day, the average daily intake of vinyl chloride by people living in the vicinity of emission sources has been estimated to range from trace amounts to 2,100μg (EPA 1979a, 1982f; Gordon and Meeks 1977). The majority of drinking water supplies in the United States do not contain detectable levels of vinyl chloride (EPA 1982f; Westrik et al. 1984). Based on this conclusion, it is estimated that the average daily intake of vinyl chloride by ingestion of drinking water for most people in the United States is essentially zero (at or below 0.028 pg/kg/day [EPA 1982fJ). Estimates provided by EPA (1985b) indicate that 0.9% of the US. population is exposed to levels of vinyl chloride in drinking water greater than or equal to 1.0 μg/L, and 0.3% of the population is exposed to levels greater than 5 μg/L.

NOES conducted by NIOSH from 1981 to 1983 estimated that 81,314 workers employed at 3,711 plant sites were potentially exposed to vinyl chloride in the United States (NOES 1990). The NOES database does not contain information on the frequency, concentration, or duration of exposure; the survey provides only estimates of workers potentially exposed to chemicals in the workplace. Exposure is believed to occur primarily through inhalation with some possible absorption through the skin (Hefner et al. 1975a).

5.6 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Individuals located near or downwind of production facilities, hazardous waste disposal sites, and landfills may be exposed to atmospheric levels of vinyl chloride higher than ambient background levels. For specific levels associated with health effects, see Section 2.7. Individuals living near hazardous waste sites and landfills may also be exposed to vinyl chloride in their drinking water. Workers involved in the production or polymerization of vinyl chloride may constitute a group at risk because of the potential for occupational exposure.

5.7 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of vinyl chloride is available. Where adequate information is not available, ATSDR, in conjunction with the NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of vinyl chloride.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

5.7.1 Identification of Data Needs

Physical and Chemical Properties. The physical and chemical properties of vinyl chloride are sufficiently well characterized to permit estimation of its environmental fate (Amoore and Hautala 1983; Cowfer and Magistro 1983; EPA 1985b; Fire 1986; HSDB 1996; IARC 1979; Lewis 1996; Lyman et al. 1982).

Production, Import/Export, Use, Release, and Disposal. According to the Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. Section 11023, industries are required to submit substance release and off-site transfer information to the EPA. The Toxics Release Inventory (TRI), which contains this information for 1993, became available in May of 1995. This database will be updated yearly and should provide a list of industrial production facilities and emissions.

Vinyl chloride is released primarily to the atmosphere via emissions from vinyl chloride and PVC manufacturing facilities (Hartmans et al. 1985; SRI 1990a, 199Ob, 1993, 1994; TR193 1995). The risk of exposure to vinyl chloride is highest for workers in the plastics industry and populations living near industrial areas or hazardous waste sites. Current production, use, and manufacturing methods are well described in the literature (Cowfer and Magistro 1985; Eveleth et al. 1990; HSDB 1996; IARC 1979; SRI 1990a, 1990b, 1993, 1994; TR193 1995; USITC 1994). More current information on releases and disposal methods might assist in estimating potential exposures to vinyl chloride, particularly for populations living near hazardous waste sites.

Environmental Fate. Vinyl chloride is transported in and partitioned to the air and water and is also partitioned to air from water (EPA 1982a). Experimental data regarding the partitioning of vinyl chloride to soil are needed. Vinyl chloride is transformed in the atmosphere by photooxidation (Carassiti et al. 1978; Cox et al. 1974; EPA 1976a; 1985c; Howard 1976; Muller and Korte 1977; Perry et al. 1977; Woldbaeck and Klaboe 1978; Zhang et al. 1983). It is removed from surface water and groundwater mainly by volatilization and photodegradation (EPA 1976a). Information regarding the transformation and degradation in soil would be helpful in defining the potential pathways for human exposure.

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Bioavailability from Environmentai Media. Vinyl chloride can be absorbed following inhalation (Bolt et al. 1977; Krajewski et al. 1980; Withey 1976), oral (Feron et al. 1981; Watanabe et al. 1976a; Withey 1976), and to a much lesser extent, dermal exposure (Hefner et al. 1975a). These routes of exposure may be of concern to humans because of the potential of vinyl chloride to contaminate air (Baker and MacKay 1985; EPA 1979a; Fishbein 1979; Gordon and Meeks 1977; Stephens et al. 1986; Wood and Porter 1987), water (Burmaster 1982; Cotruvo 1985; Dyksen and Hess 1982; Goodenkauf and Atkinson 1986; Stuart 1983; Westrick et al. 1984), and food (Gilbert et al. 1980; Williams 1976; Williams and Miles 1975). Information regarding the bioavailability from ingestion and dermal contact of contaminated soils would be helpful, particularly for populations living near hazardous waste sites, although vinyl chloride is not believed to be absorbed through skin.

Food Chain Bioaccumulation. Vinyl chloride can bioconcentrate to a limited extent in aquatic organisms (EPA 1982a; Freitag et al. 1985). Biomagnification of vinyl chloride in terrestrial and aquatic food chains does not appear to be important because of its high volatility and the fact that it is readily metabolized by higher-trophic-level organisms (Freitag et al. 1985; Lu et al. 1977). No data were located regarding biomagnification in terrestrial foodchains.

Exposure Levels in Environmental Media. Reliable monitoring data for the levels of vinyl chloride in contaminated media at hazardous waste sites are needed so that the information obtained on levels of vinyl chloride in the environment can be used in combination with the known body burden of vinyl chloride to assess the potential risk of adverse health effects in populations living in the vicinity of hazardous waste sites. Vinyl chloride has been detected in air (Baker and Mackay 1985; EPA 1979a; Fishbein 1979; Gordon and Meeks 1977; Stephens et al. 1986; Wood and Porter 1987), water (Burmaster 1982; Cotruvo 1985; Dyksen and Hess 1982; Goodenkauf and Atkinson 1986; Stuart 1983; Westrick et al. 1984), sediment (Wang et al. 1985), and food (Gilbert et al. 1980; Williams 1976; Williams and Miles 1975). Intake data for the general population from the various media are available (EPA 1979a, 1985b; Gordon and Meeks 1977; Westrick et al. 1984). Data on levels of vinyl chloride in soils are needed. Site-specific data on concentrations of vinyl chloride in air, soil, and water would be helpful in estimating the risk of exposure for populations living in the vicinity of hazardous waste sites. Also, current data on the extent of release (if any) of vinyl chloride from PVC pipes and from car interiors are needed to estimate the risk of exposure of the general population.

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Exposure Levels in Humans. Vinyl chloride has been detected in human tissues and fluids as a result of occupational exposure to the substance. No information on biological monitoring studies for the general population was located. More information on exposure levels for populations living in the vicinity of hazardous waste sites would be helpful. This information is necessary for assessing the need to conduct health studies on these populations.

Exposure Registries. No exposure registries for vinyl chloride were located. This substance is not currently one of the compounds for which a subregistry has been established in the National Exposure Registry. The substance will be considered in the future when chemical selection is made for subregistries to be established. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to exposure to this substance.

5.7.2 On-going Studies

Dr. S. Fogel (Cambridge Analytical Association) is examining the feasibility of in situ biodegradation of chlorinated ethenes, specifically vinyl chloride, in contaminated drinking water aquifers. Three microbiological processes have been identified with a high probability of achieving the complete biodegradation of vinyl chloride. The results may enable the design of a specific aquifer restoration plan in which the subsurface environment is modified to create a microbiological barrier across the path of an approaching contaminant plume. After isolating methane-utilizing bacteria that can also degrade vinyl chloride, Dr. Fogel will perform chemical analysis of the methantrophic degradation products of certain contaminants to determine whether toxic by-products are formed. In addition, he is also working with a laboratory-scale treatment column to use the methantrophic organisms for the removal of chlorinated aliphatics from waste water (FEDRIP 1994).

I. Hertz-Piccioto (University of North Carolina at Chapel Hill) is examining vinyl chloride in relation to the ability to generalize soil dispersion and biodegradation models and persistence in the environment (FEDRIP 1994). Models developed for the evaluation of biotransformation and soil dispersion are expected to be used in conjunction with epidemiological studies of populations with potential for exposure (FEDRIP 1994).

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James Swenberg (University of North Carolina at Chapel Hill) is investigating the hydrogeological and ecological factors contributing to variability in human population exposure to vinyl chloride (FEDRIP 1994). Microbial transformations that can affect toxicity and mobility of chemicals, such as vinyl chloride, in the subsurface environment will be examined. Multicomponent, multiphase flow and transport processes in subsurface systems will also be investigated.

The U.S. Department of Agriculture is funding investigations by R. Spalding and A. Drexner (University of Nebraska Water Research Center) on the remediation of vinyl chloride using small aerosols (FEDRIP 1994). The ultimate aim of the study is to determine whether sprinkler irrigation is an effective remediation technique for groundwater contaminated by vinyl chloride (FEDRIP 1994).